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A High-Performance Single-Mode Fiber-Optic Isolator Assembly

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A high-isolation single-mode fiber-optic isolator assembly has been designed and fabricated by the Time and Frequency Systems Research Group. The measured forward loss is 2.6 dB and the reverse loss (isolation) is greater than 70 dB. This is a 30-dB higher isolation than the isolation of the best fiber-optic isolator previously reported. This isolator provides isolation between the semiconductor laser diode and the optical fiber in a precise reference frequency transmission system. The isolation of the laser greatly reduces the system's sensitivity to microphonics.

I. Introduction

Reflections cause intolerable instabilities in fiber-optic systems used in some precision applications, such as the precise reference frequency distribution system being developed by the Time and Frequency Systems Research Group. These reflections have the same effect on the semiconductor laser as an unstable external cavity and result in changes in the laser's output wavelength and amplitude. External reflections must be reduced by 60 dB or more before the resulting instabilities are reduced to tolerable levels.

Optical isolators are currently used to alleviate this problem. However, the best single-mode fiber-optic isolators which have been reported have losses of 3 or 4 dB and isolation of 30 to 40 dB [1], [2], [3]. It is necessary to use two such isolators in series to obtain the isolation of greater than 60 dB required in some fiber-optic systems such as those used for precise reference frequency or microwave frequency distribution. There are two disadvantages in doing this: Good optical isolators are very expensive (around $3,000 each), and the forward loss is increased. This article describes a single-mode fiber-optic isolator assembly that provides less than a 3-dB loss in the forward direction and greater than 70 dB of isolation.

II. Fiber-Optic Isolator

The fiber-optic isolator described in this article and shown in Fig. 1 is an assembly consisting of a commercial optical isolator, an expanded-beam single-mode fiber-optic connector, and single-mode fiber pigtails.

The optical isolator used in this assembly is manufactured by Optics For Research in Caldwell, New Jersey [4]. They manufacture a variety of optical isolators using the Faraday rotator principle (see, for example, [5]). The model used in this system, IO-4-IR, is designed for use at 1300 nm operation and has an aperture of 4 mm. Isolation is specified as greater than 30 dB, and the manufacturer has stated that they have not seen one better than about 40 dB. Forward loss is specified to be less than 0.5 dB.

We have assembled the isolator with a lens system which consists of two Lamdek expanded-beam single-mode fiber connectors. These connectors permit light to be transmitted with low loss from one single-mode optical fiber to another with a gap of several centimeters between them. A plot of the optical loss as a function of the distance between connectors is shown in Fig. 2.

In this assembly the connectors mounted on single-mode fiber pigtails are placed facing each other and are separated by the appropriate distance; the optical isolator is installed between them.

III. Results

The Optics For Research isolators have much greater isolation potential than reported previously. The isolation, however, is limited by scattering due to internal reflections. The polarization of this scattered light at various locations within the isolator is not in the direction required for high attenuation. A secondary problem is presented by the nonuniformity of the polarizers across their diameters. The polarizers have a higher extinction ratio when the optical beam size is smaller because they are more uniform across a small area.

Fortunately the scattered light, which limits the isolation, is not parallel to the axis of the isolator when it exits the unit. Therefore, it can be virtually eliminated by collecting the optical output using a lens system with a small aperture and small acceptance angle.

The Lamdek expanded beam connector (data available from [6]) can provide the small aperture and small acceptance angle needed for high isolation. These connectors, when used on both sides of the isolator, set the optical beam diameter to about 1.5 mm and present a 1.5-mm-diameter aperture at the receiving fiber. The transmission loss in dB of optical power at the receiving connector is related to the offset angle of a light beam or ray by,[1]

$$\text{Loss} = 10 \log \left[e^{-(f \tan \Theta / n \omega_0)^2} \right]$$

where

f = the focal length of the lens = 7 mm

Θ = the offset angle (radians)

n = the index of refraction = 1.4995

ω_0 = 1/2 the mode field diameter = 0.00523 mm

A plot of the transmission loss as a function of the offset angle is shown in Fig. 3. At an angle of 0.0045 radians the loss is 70 dB. This accounts for the extremely large rejection of scattered light coming out of the optical isolator.

IV. Conclusion

A single-mode fiber-optic isolator has been assembled and measured for loss (2.6 dB) and isolation (greater than 70 dB). These results were achieved using commercially available components. The availability of such high-quality single-mode fiber-optic isolator assemblies will make it possible to achieve substantial improvements in precision fiber-optic systems such as those used for stable reference frequency distribution and microwave frequency transmission.

[1] Fredrick B. Messbauer of Lamdek Fiber-Optics, private communication, April 1987.

Acknowledgments

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[5] E. B. Brown, *Modern Optics*. New York: Reinhold Publ. Co. 1965, p. 125.

[6] Lamdek Fiber-Optics, 901 Elmgrove Road, Rochester, New York, 14650.

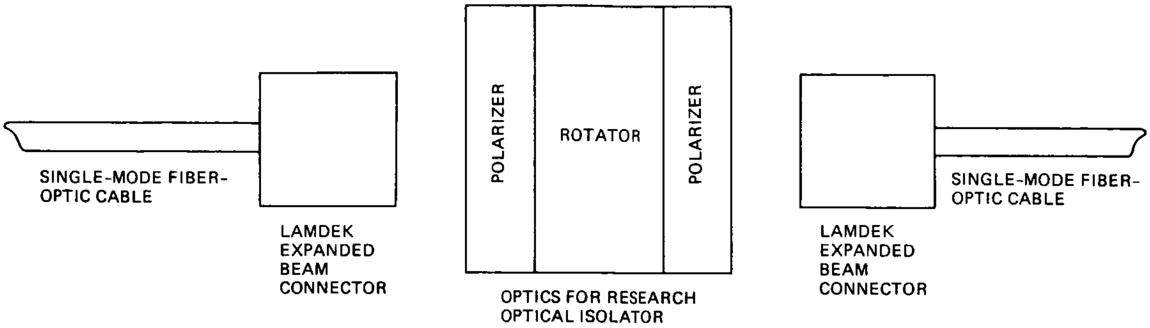

Fig. 1. Optical isolator block diagram

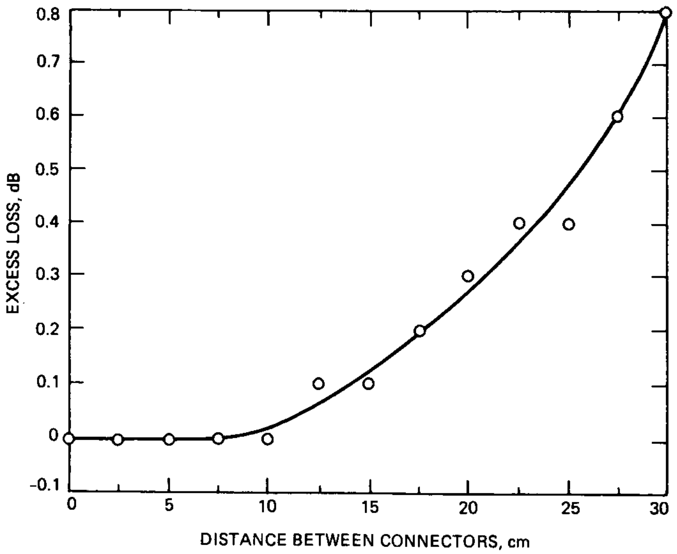

Fig. 2. Excess coupling loss as a function of the distance between the Lamdek connectors

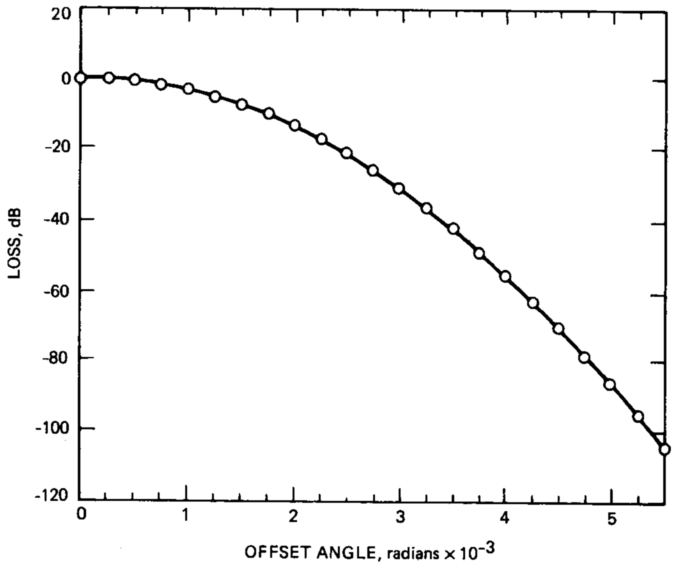

Fig. 3. Connector coupling loss as a function of the angular offset